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The Legacy of the IGY

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Editor's note: The following article is taken from a speech delivered at the 1983 Annual Meeting of the National Academy of Sciences in Washington, D.C.

Global Research Programs

We are now at the point of celebrating three milestones of international cooperation in sun-earth research: the 100th anniversary of the First International Polar Year (1882–1883); the 50th anniversary of the Second Polar Year (1932–1933); and the 25th anniversary of the International Geophysical Year (IGY) (1957–1958). Credit for the concept of the First Polar Year goes to an Austrian Lieutenant, Karl Weyprecht. He expressed the philosophy of scientific cooperation in the following bold language delivered in a statement to the Hall of the Austrian Academy of Sciences on January 18, 1875:

Purely geographical research and Arctic topography, which until now have stood in the foreground of all polar expeditions, must, with respect to the great scientific questions, recede into the background. The answers, though, will occur only when those nations pretending to aspire to the heights of contemporary, cultural endeavor decide, without regard to national rivalry, upon common measures. In order to secure decisive scientific results, we require a series of simultaneous expeditions whose aims must be, through dispersal over several points of the Arctic region and using identical instruments in line with identical instructions, to conduct a simultaneous, year-long series of observations. Only thereby shall we acquire the material for solutions to those great problems of nature that reside in the Arctic ice, and only then shall we earn the reward for those considerable resources that have hitherto been squandered in labor, endeavor, deprivation, and money in the polar region.

At the conception of the First Polar Year most countries had well-established weather services and international cooperation among these services functioned effectively. Since those countries operating weather services were mainly in North America and Europe surrounding the Arctic region, they had a common interest in the influence of Arctic ice on their weather patterns. Eleven nations combined their efforts for the International Polar Year with emphasis on weather.

Two nations sent expeditions to high latitudes with plans to study the aurora and magnetic storms as well as meteorology. They set up magnetic observatories and discovered interesting correlations between magnetic storms and auroras.

Fifty years after Weyprecht's First Polar Year, radio science had come of age and provided an exciting new capability for studying the electrified regions of the high atmosphere. Plans had been developed accordingly to conduct a Second Polar Year dedicated primarily to study of the ionosphere.

The goals of the Second Polar Year, as stated in its charter, were to study "the one or more electrically conducting layers at great heights, which are believed to be connected with radiation from the sun and the phenomena of the aurora. The aurora in turn is in some way associated with the development of magnetic storms, which form a fundamental problem in terrestrial magnetism."

The Second Polar Year was to run from August 1, 1932, to the end of August 1933. Unfortunately, those were years of the Great Depression, and the most exciting schemes for the Second Polar Year never came to pass—for example, the use of Robert H. Goddard's rockets to send instruments aloft and parachute them back to ground. Still, when the Year began, 44 nations were committed to participate. Twenty-two countries sent expeditions beyond their borders and the number of magnetic stations at high latitudes was increased from 7 to 30. The practical application of radio knowledge derived from the Second Polar Year was worth many orders of magnitude more than the total investment in conducting the scientific program.

With the end of World War II, American, British, and French research teams undertook to rocket scientific payloads to high altitudes. Until then, direct probes of the upper atmosphere had been limited to balloons. The idea for a grand campaign of ground-based and, for the first time, space-based observations of the terrestrial environment was very appealing to geophysicists. The plan to proceed with organization of an International Geophysical Year (IGY) took shape at an informal dinner party in the home of James A. Van Allen on the evening of April 4, 1950. Among the guests were Lloyd Berkner and Sidney Chapman. Chapman subsequently accepted the role of President of the Special Committee for the IGY and Berkner became vice-president. They devoted themselves to years of planning and promoting what was to become the highest level of international scientific cooperation ever achieved. The special committee met in Rome in 1954 to discuss national programs and singled out two major areas for emphasis, Antarctica and outer space. Chapman quickly expanded the scope to truly global dimensions.

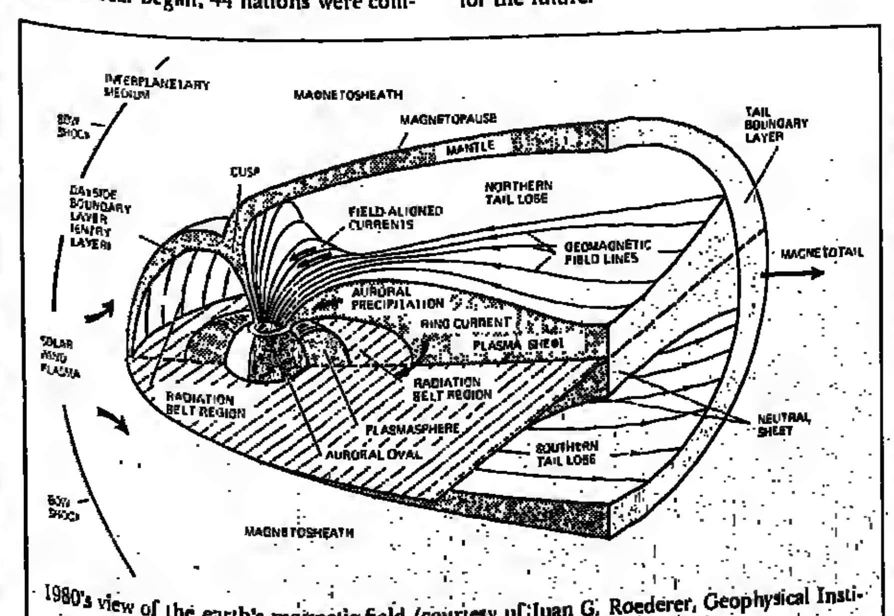
From mid-1957 to the end of 1958, 40,000 scientists and technicians from 67 nations worked at 4000 observation stations covering the earth from pole to pole. In its preparatory year, 1957, 116 rockets were launched.

The crowning achievements in space were the launch of the Soviet Sputnik in 1957, followed in 1958 by the U.S. Explorer I, which discovered the Van Allen Belts. Joseph Kaplan, chairman of the U.S. Committee for the IGY, was an enthusiastic proponent of the new space capabilities. The Antarctic program involved 12 nations: Australia, Argentina, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the United Kingdom, the United States and the Soviet Union. Forty-eight new stations were established on the margins and interior of Antarctica.

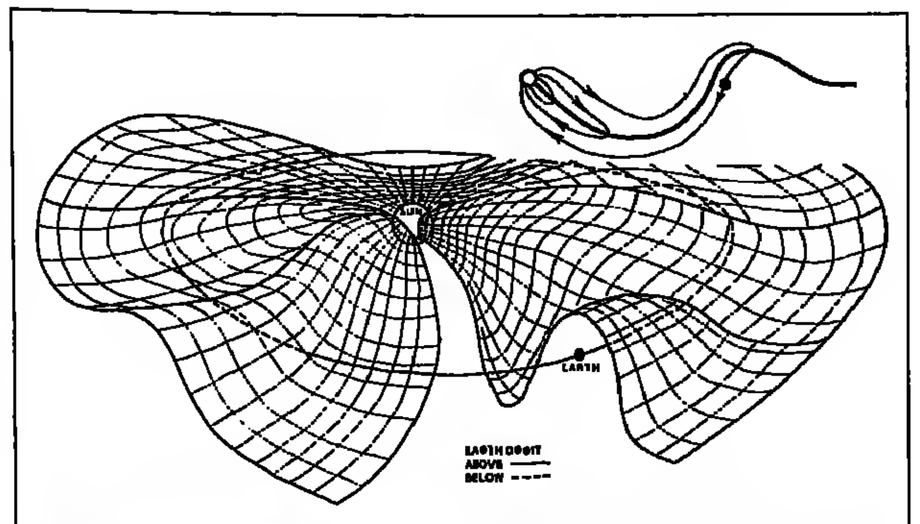
Among its outstanding successes, the IGY had a special impact on auroral research. Instead of the adventurous treks to Arctic regions by lonesome explorers with simple optical instruments, observations were organized on a widespread scale and facilities were established for rocket launchings at Fort Churchill, Canada. Auroral morphology was documented by an extensive network of all-sky cameras that covered the auroral scene from horizon to horizon. All told, there were 114 cameras in operation in the Arctic and Antarctic. Hundreds of thousands of photographs were taken at 1-minute intervals all through the night to reveal the large-scale behavior of the auroras. Auroral observations involved more amateurs than any other IGY endeavor. About 430 sky watchers fed 18,000 hourly reports on standardized forms into an Auroral Data Center at Cornell University.

By the time the IGY was completed in 1968, the power of international scientific cooperation in global research programs had been demonstrated in the most convincing fashion. There has been no thought since then of abandoning the style or the organization that was developed for solar-terrestrial research. The IGY of 1957–1958 was followed in 1964 by the International Years of the Quiet Sun and in 1976–1979 by the International Magnetospheric Study. At present, a Middle Atmosphere Program is well under way. Other notable successes have been the Upper Mantle Project and the Global Atmospheric Research Program.

In the remainder of this discussion I shall touch lightly on a number of scientific discoveries and concepts that have emerged in the geosciences in the past 25 years and mention some developments that hold special promise for the future.



1980's view of the earth's magnetic field (courtesy of Juan G. Roederer, Geophysical Institute, University of Alaska).



The "ballerina skirt" model of the solar-interplanetary current sheet (courtesy of S.-I. Akasofu, Geophysical Institute, University of Alaska).

Solar Astronomy

The Space Science Board of the National Research Council was established in June 1958, immediately in the wake of the first successful satellite launches. The Board sent some 150 telegrams to members of the scientific community soliciting proposals for satellite experiments. When the National Aeronautics and Space Administration (NASA) came into existence in October 1958, the Space Science Board was ready to offer a scientific plan for NASA to implement. The earliest successes were in the disciplines of solar astronomy and particles and fields in the neighborhood of the earth's orbit.

Solar astronomy was the primary objective of the Skylab mission launched in 1973. Imaging and spectroscopy in the full range of the spectrum revealed a variety of hot plasmas associated with flares, prominences, and tight coronal loops in sunspot regions. In the early 1950's a simplistic concept held that the corona was a large bag of superthermal gas expanded to 10^6 km above the photosphere against the pull of solar gravity. Ultraviolet and X ray imaging through the Skylab mission showed instead that most of the corona is tightly held to the sun by a cage of magnetic loops. Over the poles and over substantial regions at lower solar latitudes gaps or holes appear in the magnetic cage through which plasma can freely escape.

It may seem very surprising that we have never yet had a solar telescope in space capable of giving better optical resolution than we can get from the ground, even though the largest ground-based telescopes perform no better than a 12 inch (30 cm) telescope except under rare seeing conditions. Sunspot drawings by Galileo at the turn of the 17th century and solar granulation photographs by Janssen in 1890 are nearly as good as those obtained with the best solar telescopes today. But this situation is about to change. A Solar Optical Telescope (SOT) to be carried on the space shuttle, weighing 4000 kg and 7 m long with a primary mirror 50 inches (125 cm) in diameter, will provide 0.1 arc sec resolution. For the first time astronomers may resolve the fine structure of emerging magnetic fields on the sun.

The most recent NASA effort to monitor the solar constant began with the launch of the Solar Maximum Mission (SMM) on February 14, 1980. It carries the most advanced sensor developed thus far, called the "Active Cavity Radiometer," designed by Willson and his JPL colleagues. It has the capability of absolute measurement with a sensitivity of 0.001% for rapid variations, and its long-term, absolute stability is very good. In the first 5 months of analyzed data the evidence was clear that solar luminosity fluctuates from day to day by about 0.05%. On two occasions, over periods of about a week, the luminosity dipped as much as 0.2%. What is especially interesting about the two large dips is that they occurred just as large sunspot groups were crossing the central meridian of the sun.

Results now published through the end of 1981, representing nearly 23 months of continuous record, continue to show frequent excursions of 0.05% from average and several dips of up to 0.1%. The largest drop yet measured was 0.23% in July 1981. Over the long stretch of 18 months from February 1980 to August 1981 there was an average decrease of 0.1%. The correlation with the blocking effect of sunspots persists through all the observing period. In fact, the greatest dip coincided with the passage of the largest sunspot group of the 2 years covered by SMM operation. The area covered was 6×10^{-3} of the sun's disk—a major black-out for sunspots.

Before the IGY, little was known about the region of space beyond the shell of the earth's ionosphere. The earth's magnetic field was thought to resemble that of a simple bar magnet, and space between sun and earth was believed to be a near perfect vacuum. Since the IGY, most of the solar-terrestrial system has been sampled in an exploratory way. The picture that has emerged is remarkably complex.

In 1958, Eugene N. Parker calculated that the hot solar corona cannot be in static equilibrium. It must expand as a wind into space. Skylab images of the sun in X rays and ultraviolet light showed that magnetic field lines over the polar caps are open to space. Plasma flows freely outward in the form of high-speed solar wind and gradually turns back toward the ecliptic plane. Similarly, the open field lines above coronal holes are an escape route for fast solar wind over much of the solar disk. If we could look down on the solar pole we would observe the solar wind streams rotating with the sun. Stretched magnetic field lines would be curved into graceful Archimedean spirals like jets from a rotating garden sprinkler.

Over most of an 11-year solar sunspot cycle the magnetic field assumes the spiral form in each hemisphere but with opposite polarities. From one cycle to the next, the polarities reverse. The oppositely directed magnetic fields are separated by a thin current sheet (neutral layer) lying close to the equatorial plane of the sun.

If the flow of wind were smooth and equalized from both hemispheres, the current sheet would lie in the ecliptic plane. But the sources of solar wind are not uniformly distributed and the current sheet is warped upward and downward as it extends into the interplanetary medium. As a result, the field at any point in the ecliptic plane is not strictly radial. It can be positive or negative at angles as large as 30° to the ecliptic. According to this three-dimensional model the warped current sheet cuts across the earth like the undulating skirt of a pirouetting ballerina. At each crossing the magnetic polarity switches from positive to negative or vice versa, depending on whether the earth is above or below the current sheet.

Observations of the sun with coronagraphs in space have shown a variety of transient forms of plasma expulsion—large loops, spikes and great bubbles. Since 1979, an orbiting coronagraph mission, SOLWIND, prepared by the Naval Research Laboratory, has been acquiring a substantial body of data on coronal transients. The biggest transient expulsions have blown as much as 9×10^{12} kg of gas out of the corona. The outward speeds have ranged from 150 km s^{-1} to 900 km s^{-1}. About half of the major mass ejections are accompanied by prolonged X ray signatures, sometimes lasting as much as 9 or 10 hours. Shocks in the interplanetary medium that travel with these blobs of plasma have been frequently observed with the Helios solar probes positioned at distances of 60 to 200 solar radii above the sun's limb.

In England, Anthony Hewish has been using a 10.8-hectare (4.5-acre) antenna farm planted with 2040 small dipoles to study the scintillation of quasars. With this antenna array, pulsars were unexpectedly discovered in 1967. Plasma fluctuations between the radio source and the antenna produce the scintillations much as turbulence in the lower atmosphere makes the visible stars twinkle. Hewish has been observing a grid of 900 sources each day and can clearly track transient plasma clouds from the sun to distances beyond the earth's orbit. The combination of coronagraph, interplanetary spacecraft, and radio scintillation observations gives a comprehensive picture of transient plasma disturbances from their origin in the sun to their impact on the terrestrial environment.

Earth's Magnetic Cocoon

The new understanding of the solar wind completely alters the pre-IGY image of the earth's dipole magnetic field spreading sym-

Article, (cont. on p. 498)

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Article (cont. from p. 497)

metrically into space. The earth's field presents an obstacle in the path of the solar wind that deflects the magnetized plasma flow as in. form a cavity shaped like a comet head and tail. On the upstream side, the "nose" of the cavity is blunt and pushed inward to a minimal distance of about 10 earth radii (65,000 km) from the center of the earth. Downstream the tail stretches past the orbit of the moon, perhaps as far as 1,000 earth radii. The huge volume of plasma contained within this magnetic bag is called the "magnetosphere." It is filled with charged particles of all energies from those associated with simple heat motion to hundreds of millions of electron volts. Because the solar wind is supersonic, a bow shock stands ahead of the magnetospheric cavity. In the polar and sub-polar regions, the earth's magnetic field lines are "open" to space and offer a direct window for entry of charged particles.

When the solar wind blows across the open magnetic lines of force above the polar caps it creates a gigantic natural dynamo capable of generating 10^{12} watts at times of solar flares by developing a voltage drop of 10^5 volts and driving currents as great as 10^7 amperes. Such power is an order of magnitude greater than all the electricity consumed in the U.S. The pressure of the solar wind varies and shapes the size of the magnetospheric cavity. A sudden increase in solar wind causes the entire magnetosphere to quiver like a mass of jelly. When the magnetosphere becomes overloaded with energy from the solar wind a "magnetospheric substorm" develops and the aurora brings to light the complex processes like a live TV show. At the same time, particles are captured by the Van Allen radiation belts. The polar atmosphere under stormy magnetic conditions has been described as a great switchyard for electric current networks that flow over and through the magnetosphere.

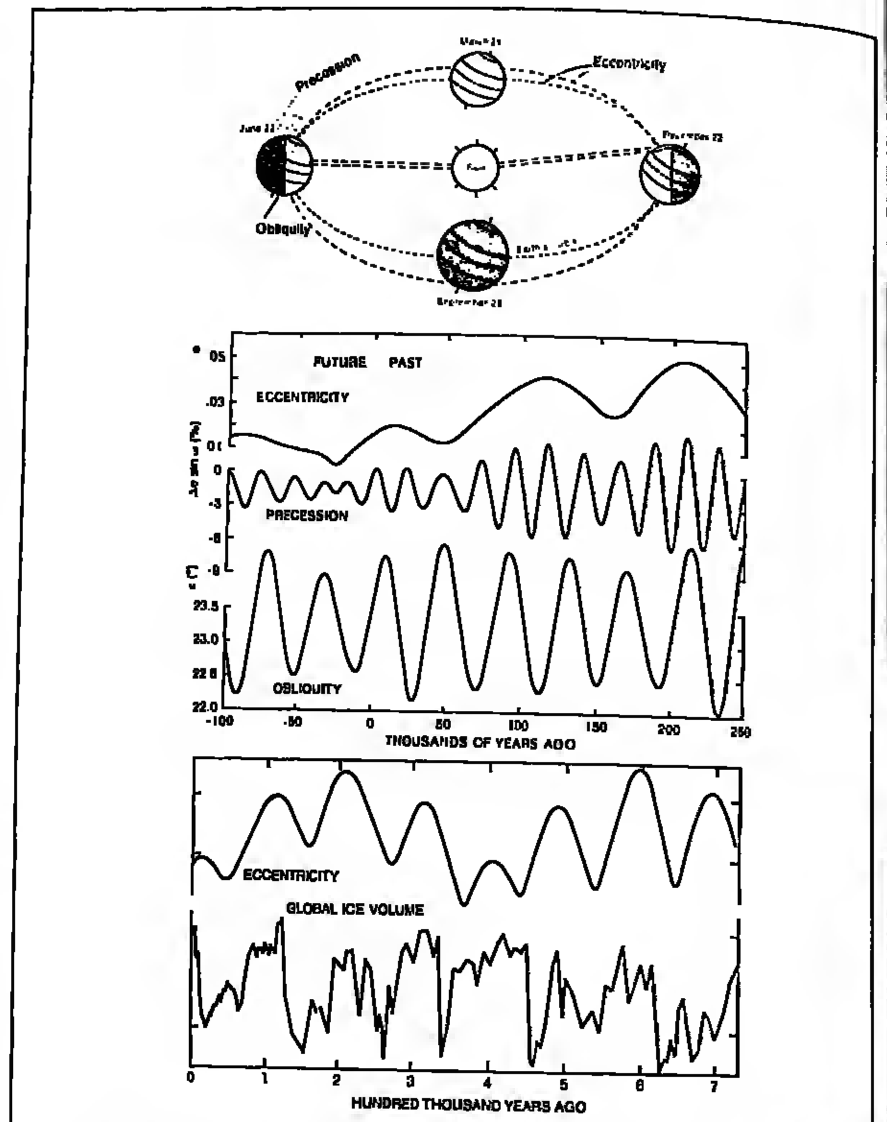
The aurora has been a source of continuing scientific puzzlement for 100 years. We have learned a great deal but a clear picture of auroral mechanisms is still elusive. Only recently have we acquired the techniques for imaging the full auroral oval from space and the results have been very surprising. Results published by Louis Frank of the University of Iowa from observations aboard the Dynamic Explorer I reveal arcs that span the polar cap and fine structure in the auroral oval itself.

In the first decade of explorations in space physics various probes were sent directly to escape through the magnetosphere or into highly elliptical orbits that made repeated traverses of the magnetospheric boundary. It was evident that such missions could not separate phenomena by spatial characteristics from temporal variations on time scales comparable to the speed of traversal. To obtain independent spatial and temporal information requires more than one spacecraft in selected spatial configurations.

The most recent effort involving a multiple array of satellites was the International Sun-Earth Explorer (ISEE) program conducted by NASA and the European Space Agency (ESA). In October 1977, NASA's ISEE 1 and ESA's ISEE 2 were launched into nearly identical orbits. As these two satellites chased each other around the magnetosphere they sensed the position and movement of the bow shock and magnetosheath about 150,000 km above earth. Where the magnitude field lines dragged from the sun by the solar wind merged with those of the earth's magnetic shield, the magnetosphere appeared to suffer a ripping of its surface. The solar wind's magnetic field merged with the earth's field on the sunward side of the magnetosphere and tore back the magnetospheric field, peeling it off toward the dark side of the earth, hundreds of thousands of kilometers into the magnetospheric tail. As merging of the interacting fields progressed, the field lines were sharply bent, and particles caught inside the bends were accelerated as though projected by a sling shot.

In August 1978, NASA launched ISEE 3 to a vantage point 1.5 million km above earth where it monitored the solar wind on its way to the magnetosphere. Instead of orbiting the earth, the satellite executed small circles in the gravitational well known as the L_1 libration point between the sun and earth. From this outpost ISEE 3 sensed the solar wind in time to give advanced warning of the outbreak of magnetic storms and auroras.

For the next round of magnetospheric research, space plasma scientists have conceived a program called Origin of Plasmas in the Earth's Neighborhood (OPEN). Not yet an approved mission, OPEN would involve a minimum of four spacecraft: (1) the Interplanetary Physics Laboratory (IPL), (2) the Polar Plasma Laboratory (PPL), (3) the Equatorial Magnetosphere Laboratory (EML), and (4) the Geomagnetic Tail Laboratory (GTL). The IPL would be placed in a "halo" orbit around the sun–earth L_1 libration point. The GTL would arrive at an apogee location in the distant geomagnetic tail by using lunar swing-by maneuvers. It would be possible to vary the apogee from 80 to 250 earth radii. The PPL would start out in a polar orbit with an initial apogee at 15 earth radii and would work its way in to 4 earth radii 18 months later. The EML would vary its position from 2 earth radii to 12 earth radii in the magnetotail, while simultaneous data would be received from the GTL. With such a variety of configurations of the four spacecraft, a great variety of couplings in the solar-wind/magnetosphere/ionosphere system could be explored.



The geometry of the earth's orbit (top) changes over 22,000-, 41,000-, and 100,000-year cycles (center). The curve for orbital eccentricity tracks with changes in global ice volume over the past 730,000 years (bottom), with the latter determined by the ratio of oxygen-18 to oxygen-16 in fossilized plankton. (Figure based on National Science Foundation's *Mosaic*, *10*(6), 2–8, 1979, from a paper by J. Imbrie and J. Z. Imbrie.)

Sun and Climate

With a host of complex factors operating on climate is it possible to identify any control that is clearly associated with variability of solar insolation? A remarkable connection has come to light through the brilliant efforts of a Yugoslavian mathematician, Milutin Milankovitch. His scientific career from 1921 to 1941 was totally dedicated to solving the connection between the varying shape of the earth's orbit, the tilt of the spin axis and its slow precession and the variations in global climate over the ages. His goal was to produce an astronomical theory of ice ages and he succeeded to a very large extent.

The changing seasons of the year result from the tilt of the earth's equatorial plane from its orbital plane. At present, this angle of obliquity is 23.5°, but it varies slowly between 22.1° and 24.5°. In the 1930's, Milankovitch proposed that this gentle nodding of the earth's axis would create a 41,000-year global temperature cycle. Besides moving back and forth, the earth's axis of rotation also wobbles. This motion produces a precession of the equinoxes, which slowly varies the relative lengths of winter and summer. According to present theory the precession induces a 22,000-year temperature cycle. More recent analyses also point toward climatic influence stemming from the changing eccentricity of the earth's orbit. In a 100,000-year cycle the orbit stretches from being almost perfectly circular to being slightly elliptical and back again. But the greatest range of this effect on the annual solar flux received at the earth is only about 0.1%.

A research project known as CLIMAP (Climate: Long-Range Investigation, Mapping and Prediction), conducted by an international team of scientists in the 1970's, has verified the link between climatic change and orbital geometry. The results are based on new isotope techniques to analyze core samples of ocean sediments that contain a record of prehistoric temperature variations. The 22,000-year precession cycle, the 41,000-year tilt cycle, and the 100,000-year eccentricity cycle have all been confirmed. Over the last million years, there is evidence for at least 10 major glaciations interspersed with several little ice ages, but the connection between terrestrial solar flux and climate is not simple.

The firm evidence that orbital factors alone create a terrestrial climate response in time with the ice ages even though the total variation of insolation amounts to only 0.1% is perhaps the most puzzling evidence of a sun-climate connection. Astrophysicists are confident of their models of stellar evolution according to which the sun grows steadily more luminous with time. Since its birth, the sun has grown 40% brighter. Atmospheric scientists, however, find it difficult to reconcile the apparent increasing luminosity of the sun with their concepts of climate. According to their views, if the carbon dioxide content and relative humidity of the atmosphere were unchanged over the lifespan of the earth, it should have been totally covered with ice from 4.5 to 2.3 billion years ago because of the weaker flow of sunlight and heat. But several sources of geologic evidence offer convincing proof that life has existed on earth for the past 3.5 billion years and that water oceans have covered most of the earth for at least 3.8 billion years. With all we understand of climatology this discrepancy between solar luminosity and global temperature cannot be easily explained—we cannot model the net response of the climate system to such a change in solar luminosity with any precision. Somehow the atmosphere of the early earth must have adjusted to the lower solar intensity to prevent global freezing. One possible avenue of escape from the dilemma is the evolution of carbon dioxide. With little plant life and vegetation, the conversion of CO_2 to oxygen by photosynthesis would have progressed very slowly, leaving an atmosphere very rich in CO_2. The resulting greenhouse effect would have kept the earth warm like an insulating blanket. But very large changes in CO_2 are required to produce such substantial changes in surface temperature. If, for example, the present CO_2 content were doubled, it is estimated that the surface temperature over most of the earth would increase by only a few degrees C.

Atmosphere, Oceans, and Lithosphere

Our understanding of the various regimes of the atmosphere from the thermosphere to the troposphere has become highly sophisticated, but with sophistication has come a recognition of more and more complex scientific questions. At high altitudes and near ground in situ measurements are readily feasible, but in the middle-altitude ranges we have only recently begun to prepare satisfactory probes. A balloon payload designed by Harvard scientists can, by means of a winch and cable, lower an automatic laboratory half the distance from the stratosphere to ground. Its inventors call the payload the "monkey." Walter Sullivan of *The New York Times* described it as the world's largest yo-yo. NASA has plans for tethered payloads to be lowered from the space shuttle down to altitudes where air drag would make it impossible for a free-flying satellite to survive even one orbit. In the future there should be no regime of the atmosphere into which laboratories cannot be introduced for direct measurements.

Since the time of the Challenger expedition in 1871, ocean scientists have sought to map the ocean currents. In spite of many dedicated efforts the deep circulation is still not known. Even though oceanographic instruments are vastly improved, an oceanographic ship typically moves at about 10 knots. This is much too slow to keep up with synoptic changes.

Deep moorings and drifters have been the principal measurement techniques for the past 20 years. Surface drifters communicate via satellite and deep sea drifters are picked up by acoustic listening posts. With these methods it has become clear that the ocean's dynamics are every bit as complex as those of the atmosphere. Drifters reveal a pattern of basin-wide general circulation on the larger scale and a variable mesoscale of the order of 100 km that is the ocean weather pattern. Then there are 10 km fronts and 1 km internal waves. In the end, energy from the wind and sun is dissipated at a millimeter microstructure. All these elements of the system are coupled dynamically and must be studied collectively as a system.

Improved knowledge of the general circulation of the oceans is critical to our understanding of the earth's climate and its fluctuations. Fundamental to achieving this understanding is ocean satellite technology: radar altimetry to measure ocean currents and scatterometry to measure the stress exerted by winds on the oceans. SEASAT scatterometry and altimetry have demonstrated the ability to infer sea stress to mesoscale resolution. When satellite measurements are augmented by air-dropped instruments, surface and submerged drifters and remote acoustic sensing, a powerful scientific attack on ocean dynamics is possible.

Important elements now in planning are the Ocean Topography Experiment (TOPEX) of NASA and the Navy's Remote Ocean Sensing System (ROSS). The World Ocean Circulation Experiment (WOCE) represents planning for a new sampling strategy that includes all of the elements I have just mentioned.

When we understand how the ocean moves, we may begin to understand the great variability (in space and time) of life in the oceans and why world climate and its fluctuations are so intimately linked to the oceans.

The earth is far from the static, unchanging body it appears to be. It is more aptly described as the "restless earth"—constantly evolving because of the steady loss of heat from the interior. Global tectonic movement proceeds at a creep rate about as fast as the growth of a fingernail; drift of the magnetic field goes to the point of reversal on a million year time scale; and earthquake and volcanic activity develop catastrophically.

At the time of the IGY, plate tectonics was only a gleam in the eyes of solid earth geophysicists. Now we are in the midst of a plate tectonics revolution already two decades old. According to current views, the outer 100 km of the solid earth—the lithosphere—is broken into about 20 nearly rigid plates. Convection currents in the hot, semiplastic mantle underlying the crust lift and crack the plates and push them horizontally at the same time. The lighter continental crust rides on top of the plates. At mid-ocean ridges, plates drift apart and molten magma oozes up to form new lithosphere. Where plates collide at convergence zones, the heavier one subsides under the other and plunges back into the mantle, where it is fused and recycled; the lighter continental crust is uplifted to form mountain ranges. Tectonic processes have not only shaped the crust but also localized mineral and hydrocarbon concentrations. Resources are often found in geologic structures in the crust that may give rise to anomalies in the satellite-observed magnetic and gravity fields.

The technology for the study of the slow creep of plate tectonics has been advancing figuratively by leaps and bounds. Very Long Baseline Interferometry and laser ranging make possible detection of rates of movement as small as a few centimeters per year. A powerful new interferometer facility for radio astronomy, the VLBA, is expected to come on line in this decade. It is composed of eight telescopes arrayed across the contiguous 48 states of the United States, one in Hawaii, and one in Alaska. Not only will it serve radio astronomy, but it will be a powerful geodetic facility that will improve the detectability of crustal movements by an order of magnitude.

Since a continental array can be extended to intercontinental dimensions, both radio interferometry and laser ranging lend themselves admirably to international cooperation. Already, 14 satellites equipped with reflectors have been launched by the United States and other countries. Reflectors have been placed on the moon, and a space-borne, upside-down laser system will be carried on the space shuttle. The laser in space would range down to hundreds of reflectors on the ground. As crustal movement forces displacements of the reflectors relative to each other the pattern of return pulses will vary accordingly. A single, shuttle-borne laser ranger could service a world-wide community.

When it begins service, in 1987, the U.S. Department of Defense's Global Positioning System will also be able to monitor crustal deformation. Mobile receivers on the ground are being developed to determine relative positions with high accuracy in only a few hours of observation.

At the time of the IGY, there was considerable interest in relating solar flares and terrestrial magnetic storms to variations in the length of day, but the technology then was insufficient to demonstrate convincing correlations. Over geological time spans the earth's rotation rate slows down because of tidal forces between the earth and moon. Superimposed on this trend is a clear, annual variation of about a millisecond, directly attributed to the seasonal change of angular momentum of the atmosphere. On top of this regular cycle are small fluctuations which may represent solar terrestrial couplings. The new generation of VLBI and Laser Ranging should be able to isolate clearly such sporadic influences. Longer-range trends may provide clues to internal dynamics of the earth.

Summary

The success of the IGY has prompted contemporary geoscientists to consider the possibility of a second-generation IGY, to which we have tentatively given the name International Geosphere-Biosphere Program (IGBP). Biosphere studies were essentially neglected during the IGY but concern for the environment has heightened our awareness of the need for understanding of atmospheric pollutants and biogeochemical cycles, and of the links between geophysical and biological processes.

IGBP is still an unstructured concept. It is essential that the programs planned be global in character to derive substantial benefits from international cooperation. The science involved must have strong cross-disciplinary content to connect the diversity of scientific subdisciplines that constitute the whole of geoscience.

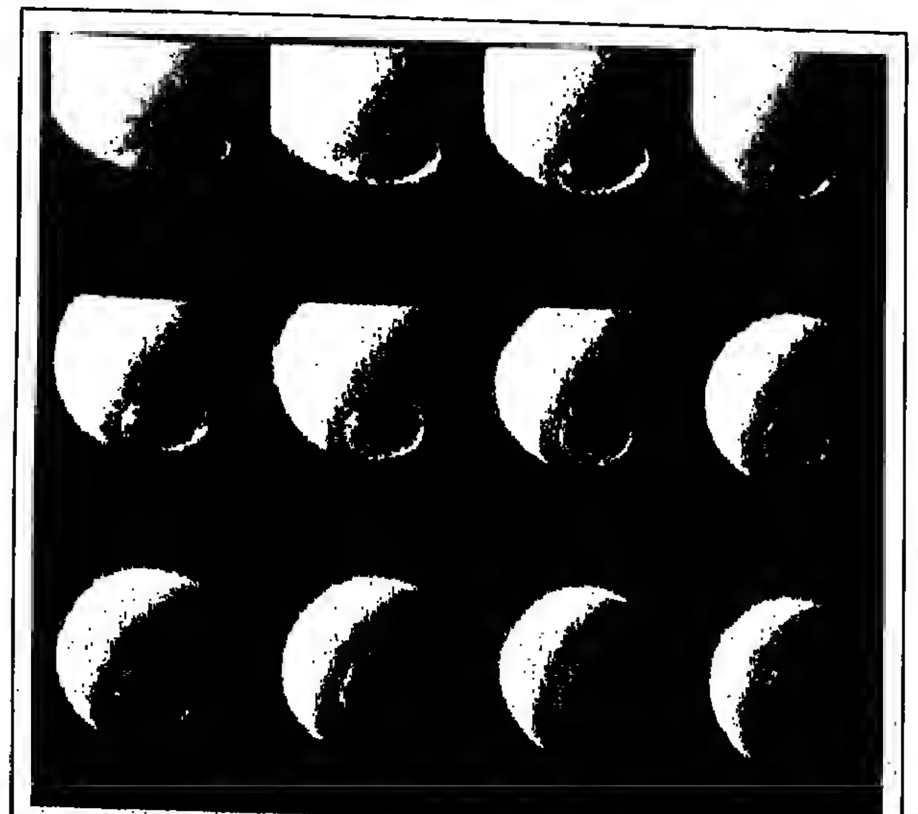
It is possible to frame scientific programs of a global character with well-defined emphases in several major categories, i.e., solar-terrestrial relationships, lithospheric dynamics, oceans and atmosphere, and the biosphere. Within each of these major blocks of geoscience the value of organized international cooperation is unquestioned. In each major block many special projects are already planned or under active consideration. The question we raise is whether a general umbrella plan for all of these major blocks of geoscience can be formulated to enhance the cross-disciplinary exchange of ideas in such a way that the totality of scientific progress will be greater than the sum of the constituent parts.

If we search for cross-disciplinary connections they turn out to be more common than uncommon. Let me offer some examples, using such widely separated elements as the sun and the earth.

- We learn about the interior of the earth from seismology. In the past decade, solar physicists have taken their cue from seismologists and used observations of solar vibrations to learn about the interior of the sun.
- NASA has on the drawing board a project called "Starprobe" which will approach within 4 solar radii in a highly eccentric orbit and measure the mass distribution of the solar interior just as geodesists have done for the earth and lunar orbiters for the moon.
- Solar magnetism is related to its internal spin and convection much as we believe terrestrial magnetism derives from rotation and convection in the earth's liquid core. Solar magnetism reverses every 22 years, terrestrial magnetism every million years. The similarities, in principle, of the physical processes are impressive.

Unlike the IGY, which was planned to run less than 2 years, the IGBP must be designed to cover one or two decades because many of the natural geosphere-biosphere cycles are that long or longer.

IGY contributed greatly to international understanding, but the stimulus for international cooperation has been wearing thin over the years. I believe we should try to revive it again.



Twelve consecutive images at ultraviolet wavelengths record the formation of the newly reported auroral configuration, the "theta" aurora. The sequence begins at 1158 UT on November 8, 1981, at top left. The northern auroral zone is at large slant angles as the NASA/GSFC spacecraft Dynamics Explorer I views the morning side at low northern latitudes and proceeds outbound towards apogee at polar latitudes. A polar arc is first defined clearly at 1247 UT (fifth image, second row, left). Note that the arc of the auroral configuration is similar in intensity and width to the aurora of the oval, and that it extends continuously across the polar cap (courtesy of Louis A. Frank, Department of Physics, University of Iowa).

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Cover. LANDSAT image (red band) of a portion of the Kunlun fault located in Western People's Republic of China. The area shown is roughly 200 km × 200 km. Note the intersecting faults near the center of the photograph and extensive fan development at the top of the image. (Photo courtesy of Joseph R. Presig, Department of Geological Sciences, State University of New York, Binghamton, NY 13901.)

News

S_2 Discovered in Comet

The recent approach of comet IRAS-Araki-Alcock (1983d) to within 5 million km of earth on May 11, 1983, was an unprecedented opportunity to study processes occurring within the coma close to the nucleus of a comet (*Eos*, June 28, 1983, p. 429). It was also a formidable observational challenge since, at closest approach, the angular motion of the comet was 40° per day. The International Ultraviolet Explorer (IUE) Observatory (*Eos*, June 3, 1980, p. 481) operated from the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center, was able to meet the challenge and provided Paul D. Feldman of the Johns Hopkins University and Michael F. A'Hearn of the University of Maryland with an unexpected discovery—the presence of S_2 in the comet.

Because of excellent advance planning by the IUE Observatory staff, it was possible to acquire the comet very quickly, track it reliably, and begin exposures within an hour of the start of the shift. Exposures with the mid-ultraviolet spectrograph (covering 200 to 340 nm) in low dispersion mode immediately showed more than a half-dozen emission features between 280 and 310 nm never before seen in comets. These are visible only within a diameter of ~100 km of the nucleus, the spatial resolution of the IUE Observatory when the comet was 0.032 AU from earth (which is probably why they have never been seen before), and have been identified as being due to diatomic sulfur (S_2). A preliminary analysis suggests that the production rate of S_2 is of the same order as the production of CS, the only other sulfur compound known in comets. As far as is known, S_2 has never been seen in any other astronomical source. Because of the close confinement to the region near the nucleus, it seems likely that S_2 comes directly from the nucleus, unlike virtually every other species observed in comets. Moreover, CS, which is believed to be the principal dissociation product of CS_2, was observed to have a much larger spatial extent than S_2, as is expected for a "daughter" molecule.

The discovery of S_2 in cometary ice provides a new clue for the study of the evolution of these minor members of the solar system. The short photodissociation lifetime of S_2 (estimated at 500 seconds) also makes it an invaluable probe of short-term variations in the activity of the cometary nucleus. A detailed spectroscopic analysis of the S_2 emission is being prepared for publication.

Observing time on the IUE Observatory is shared among NASA, the U.K. Science and Engineering Research Council, and the European Space Agency.

This news item was contributed by Paul D. Feldman of the Department of Physics, Johns Hopkins University, Baltimore, MD 21218.

Love Canal Questions

The Environmental Protection Agency (EPA) conducted a 3-month monitoring study of the Love Canal area near Niagara Falls, N.Y., after the federal government pronounced that a potential health risk existed due to chemical waste dumps. In 1982 the Department of Health and Human Services (HHS) decided that the area was habitable, subject to implementation of effective safeguards against leakage from the canal and to cleaning up of the contaminants. Now, the Congressional Office of Technology Assessment (OTA) has announced that, with the information available, it is not possible to demonstrate with certainty that unsafe levels do not exist within the so-called "emergency declaration area" (EDA).

The OTA findings can be summarized as follows:

- Current activities and long-term plans for EDA cleanup and operation and maintenance of the Love Canal remedial action program are not entirely satisfactory.
- Design of the EPA monitoring study, particularly its sampling strategy, was inadequate to detect the true level and pattern of toxic contamination that might exist in the EDA.
- EPA's monitoring study contains important uncertainties over the levels of the toxic chemicals detected and the possible levels of those not detected. There are also uncertainties about possible synergistic human health effects of multiple toxic chemicals present at low concentrations. These two areas of uncertainty, as well as the lack of detailed documentation by HHS of its analyses, place HHS's decision on habitability in doubt.
- OTA's analysis of the data obtained in the EPA monitoring study for those chemicals known to have been disposed in Love Canal provides limited, but not conclusive, indication that there may be contamination in the EDA by toxic chemicals from Love Canal.

The experience gained in the analysis of Love Canal may be valuable in the use of the "Superfund" created by Congress to clean up hazardous waste sites. Some 16,000 uncontrolled, hazardous waste sites have been identified nationwide. The OTA Technical Memorandum (#52-003-00917-0, U.S. Government Printing Office, Washington, D.C., 1983) contains the analysis. In summary, monitoring guidelines must be established as follows:

(1) Examine the "How clean is clean?" questions, and develop standards for unacceptable levels of contamination by toxic chemicals.

(2) Obtain more information on the health effects of toxic chemicals, and better define the federal decision making process concerning habitability and relocation of residents from uncontrolled hazardous waste (3) Develop technical guidelines for monitoring studies, particularly for sampling and analyses, and for the way results are presented and documented.

(4) Consider replacing waste containment "interim solutions" with more permanent solutions for cleaning up uncontrolled waste sites, and improve oversight by EPA of state implementation of chosen remedial action programs.

(5) Explore answers to problems of long-term institutional effectiveness such as mechanisms to assure indefinite funding for operation and maintenance of waste containment systems.—*PMB*

Color Experiment in JGR-Red

A special issue of the red section of the *Journal of Geophysical Research* that will feature liberal use of color at special reduced rates is being planned for July 1984. The first goal is to determine the need for color graphics from authors' and readers' viewpoints. The second goal is to gain experience with economies of scale so that realistic page charges can be set.

Figures should be submitted in the final size. JGR page maximum dimensions are 17.3 cm × 24.3 cm. Both the figure and the caption must fit on the page.

Regular JGR page charges will apply to text pages. Special rates for the color pages apply to this issue only.

- If press-ready color separation negatives and a color proof, such as a Cromalin, are supplied, the cost will be $170 per page of color.
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News (cont. on p. 500)

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News (cont. from p. 499)

Geophysical Events

This is a summary of *SEAN Bulletin*, 8(6), June 30, 1983, a publication of the Smithsonian Institution. The complete bulletin is available in the microfiche edition of *Eos* as a microfiche supplement or as a paper reprint. For the microfiche, order document E83–007 at $2.50 (U.S.) from AGU Fulfillment, 2000 Florida Avenue, N.W., Washington, DC 20009. For the paper reprint, order *SEAN Bulletin* (giving volume and issue numbers and issue date) through AGU Separates at the above address; the price is $3.50 for one copy of each issue number for those who do not have a deposit account, $2 for those who do; additional copies of each issue number are $1. Subscriptions to *SEAN Bulletin* are available from AGU Fulfillment at the above address; the price is $18 for 12 monthly issues mailed to a U.S. address, $28 if mailed elsewhere, and must be prepaid.

Volcanic Events

Kilauea (Hawaii): Lava flows and spatter cones produced by 2 new phases of E rift zone eruption
Etna (Italy): Lava production continues but at lower rate; central crater explosions; lava temperatures
Veniaminof (Alaska): Lava flows melt holes in caldera ice; increased ash emission
Mt. St. Helens (Washington): Lava dome continues to grow
Long Valley (California): Earthquake swarms but no deformation changes
Bulusan (Philippines): 2 small phreatic explosions from summit crater
Langila (New Britain): More frequent vulcanian explosions
Manam (Bismarck Sea): Seismicity stays high; emissions, noises lessen
Ulawun (New Britain): 5 periods of volcanic tremor
Ruapehu (New Zealand): Lake water characteristics unchanged; deflation
El Chichón (México): Slight decline in stratospheric aerosols; long-term lidar data from Germany and Virginia summarized
Atmospheric Effects: Fresh volcanic material sampled in lower stratosphere; lidar data shows new layer near tropopause

Kilauea Volcano, Hawaii, USA (19.42°N, 155.27°W). All times are local (= UT−10 hours). The following report is from the USGS Hawaiian Volcano Observatory:

"The fourth and fifth major eruptive phases of Kilauea's E rift zone eruption occurred during June and early July and produced 3 new major lava flows that extended SE down the S flank of Kilauea volcano. The eruptive vents for both episodes were located just within the Hawaii Volcanoes National Park about 15 km ESE of the summit caldera rim. The same vents had been active intermittently since early January.

"Lava fountains of the fourth phase were first reported at 1025 on June 13. At midday, a 100-m-long line of low fountains was feeding flows to both NW and SE. The NE end of the vent quickly became the major locus of lava production, and an aa flow fed by a vigorous river of pahoehoe began extending SE, overlapping the late March (phase 3) flow. A steep-sided spatter cone 30–40 m high was built at the source of the flow, which cascaded over a spillway ½ to ⅔ of the way up the S side of the cone. A low fountain, up to about 20 m high, rose from the lava pond that filled the interior of the cone to the level of the spillway.

"Discharge of lava was estimated to be approximately 100,000 m³/h. The main flow extended about 7.5 km SE from the vent and covered approximately 1.5 million m². Its front advanced from about 30 to 200 m/h. Following the National Park boundary, the flow entered the Royal Gardens subdivision only locally and no homes were destroyed. Phase 4 ended abruptly at 1413 on June 17. Like previous 1983 lavas, the phase 4 basalt is slightly porphyritic with small phenocrysts of plagioclase and olivine. Lava temperatures measured by thermocouple ranged from 1115 to 1132°C.

"Phase 5 began on June 29. At 1000, a pool of lava was seen slowly rising inside the main vent of phase 4. At about 1300 lava production became vigorous, and phase 5 lava cascaded over the earlier spillway and began flowing SE within the previously evacuated phase 4 channel. Lava production quickly reached and stayed at a rate of about 100,000 m³/h, and an aa flow began advancing SE over the basalts of phases 3 and 4. Advancing at average rates ranging from 80 to 165 m/h, the flow front entered the NW part of the Royal Gardens subdivision at 1919 on July 1. It finally stopped 8 km from the vent at about 1030 on July 3, after destroying seven dwellings and cutting off four others from road access. The average velocity of the flow moving down the 4–8° slopes of the subdivision was 56 m/h, but the actual velocity ranged from 0 to 80 m/min. Periods of stagnation up to a few hours long alternated with rapidly moving surges that advanced the flow front by 100–300 m in 30 min.

"At about 1600 on June 29 a satellite vent on the W flank of the main vent began erupting. For the next 24 hours it supplied local pahoehoe flows that extended about 1 km N and NE of the vent. Then the satellite vent stopped feeding flows to the north and began to feed an aa flow that extended 5 km SE along the SW edge of the phase 3 and 4 flows. It, too, was fed by a pahoehoe channel; the front of this flow advanced at average rates of 70 to 110 m/h.

"Fountain activity at the phase 5 vents constructed a pair of juxtaposed spatter cones about 40 m high. Lava pond surfaces within the 2 vents were 20–30 m above the bases of the cones. Spatter was ejected to about 50 m above the pond surfaces, and fountaining was more vigorous than in phase 4, which suggested that the phase 5 magma may have been less depleted in gas. Measurements by thermocouples gave lava temperatures of 1127–1129°C. Basalt collected near the end of phase 5 may be compositionally different from lavas erupted in previous phases. Millimeter-size olivine phenocrysts are abundant, and plagioclase phenocrysts are rare. Lava production at the vents stopped at 0717 on July 3.

"Water-tube tilt measurements at the summit (Uwekahuna) showed small but distinct episodes of deflation that correlated with phases 4 and 5. Minimum volume loss at the summit was estimated to be about 14 x 10⁶ m³ for phases 4 and 5 combined. Very low level harmonic tremor has characterized the periods between eruptive phases. On June 13, coincident with phase 4, tremor increased during the period from 0500 to about 1100. It remained constantly high until 1400 on June 17. Again, coincident with phase 5, tremor amplitude increased beginning at about 0900 on June 29, remained high through the eruption, and dropped dramatically from 0713 to 0720 on July 3."

Robert Symonds measured a rate of SO_2 emission from Kilauea of 7200 tonnes/d from the ground on June 30 and the same flux from the air on July 1.

Information Contacts: Edward Wolfe, Arnold Okamura, and Robert Koyanagi, USGS Hawaiian Volcano Observatory, Hawaii Volcanoes National Park, HI 96718 USA. Robert Symonds and Tom Casadevall, USGS Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, WA 98660 USA.

Atmospheric Effects

Recently erupted volcanic material from an unknown source was collected at 18–19 km altitude over the western United States during a series of flights by a NASA U-2 aircraft April 22–29. Samples from an April 22 mission flown at 37°N from near San Francisco (about 37.7°N, 122.5°W) to Topeka, Kansas (39.02°N, 95.68°W), included particles ranging from less than 0.1 micron to 20–30 microns in diameter: fragments of magnesian olivine, Cl-rich agglomerates, and H_2SO_4 droplets, plus a few glass shards, fragments of SiO_2, and particles of copper and zinc oxide. The copper oxide–zinc oxide particles were similar to those found in previous aircraft samples of volcanic debris, with a characteristic 2:1 Cu to Zn ratio. During a flight from Topeka southward to Palestine, Texas (31.75°N, 95.65°W), on April 28, concentrations of volcanic material were less than on April 22 but remained above background levels. However, flying northward from Topeka to the U.S.–Canada border (49°N) the next day, particle concentrations were substantially higher, and the debris included many large fragments.

The source of the volcanic material remains uncertain. The samples were not chemically similar to ejecta collected from the El Chichón aerosol cloud, and Raymond Chuan added that the large size of some of the particles suggests that the eruption probably occurred no more than about 2 months before the late April flights. Some large particles had been found in July 1982 samples from the El Chichón stratospheric cloud but none were recovered during flights in November 1982. Chuan also noted that a mid- to high-northern latitude source for the April 1983 material is suggested by the higher concentration of volcanic debris on more northern flight paths. No observations of early 1983 eruption clouds large enough to penetrate the stratosphere have been reported to SEAN. However, the largest clouds from the April 8 eruption of Asama (Japan, 36.40°N, 138.53°E) were produced before dawn and were not observed (see *SEAN Bulletin*, 8(3–4)). Ashfall from this eruption extended more than 250 km to the ENE, reaching the coast of Honshu. Large plumes from Etna (Italy, 37.73°N, 15.00°E) have been observed from the ground and on satellite imagery during the eruption that began March 28 (see *SEAN Bulletin*, 8(3–5)).

Information Contacts: Raymond Chuan, Brunswick Corp., Costa Mesa, CA 92626 USA; David Woods, NASA Langley Research Center, Hampton, VA 23665 USA.

Earthquakes

Date	Time, UT	Magnitude	Latitude	Longitude	Depth of Focus	Region
June 11	0310	$5.4M_L$*	36.26°N	120.47°W	2 km	Cent. California, USA
June 21	0626	$6.9M_s$	41.25°N	139.26°E	Shallow	Sea of Japan
June 24	0758	$6.0M_s$	21.78°N	103.37°E	shallow	NW Vietnam
June 24	0906	$6.5M_s$	24.32°N	122.58°E	shallow	E of Taiwan

*$5.0M_L$, University of California, Berkeley.

Information Contact: National Earthquake Information Service, U.S. Geological Survey, Stop 967, Denver Federal Center, Box 25046, Denver, CO 80225 USA.

Meteoritic Events

Fireballs: Germany; E central, SE Michigan, mid-Atlantic, W Oregon, USA.

Books

Solar Variability, Weather, and Climate

National Research Council, *Stud. in Geophys.*, National Academy Press, Washington, D.C., 1982.

Reviewed by A. Berger

Solar Variability, Weather, and Climate reassesses the question of solar variability and its effects on weather and climate, taking into account new measurements and more recent theories of the earth's atmosphere. The papers, which make up this book, were presented at an American Geophysical Union meeting in December 1978. Besides a review of the current basic knowledge on the topic, fundamental questions requiring additional research form the basis of the conclusions and recommendations.

Eight papers, five stating the background and three the possible mechanisms, comprise the book. Solar, weather, and climate variability and evidence of the effect of solar variations on the atmosphere are reviewed. Solar variability is recognized to exist at different time scales (from minutes to decades), and these variations cover a broad range of the spectral irradiance (from X rays and extreme ultraviolet to the centimeter wavelengths). Regarding total luminosity, the parts of the solar constant that are known to vary constitute less than 1% of the total budget of energy that the earth receives from the sun and is far less than the total energy required to force direct changes in atmospheric circulation. Moreover, the variable portions of the solar output are mainly absorbed or dissipated in the upper atmosphere. Thus, for known solar changes to perturb the dynamics of the troposphere they must work through mechanisms that are complex and indirect. A number of such possible dynamic, radiative, chemical, and electrical couplings of solar inputs through various regions of the atmosphere are discussed in chapters 6, 7, and 8.

The revival in both weather and climate predictions requires undoubtedly a deeper physical understanding of the causes of atmospheric variability. Because of the obvious importance of the sun, which drives the earth's atmospheric circulation, research in solar variability has always been popular. However, models trying to relate solar activity (usually understood as short-term variations in the output of the sun) to weather and climate variability are few, are oversimplified, or are only descriptive. Statistical studies failed to give unequivocal answers to the impact of solar variability on either weather or climate: A very small percentage of the climatic variance can be explained, and apparent correlations have failed when tested with different data sets.

Critical examination of most of the investigations published up to now show clearly how much the following needs must be met: (1) use of adequate statistical tests and of powerful objective techniques of data analysis; (2) an improved theoretical understanding of the inherent causes of solar variability and of the relationship between the terrestrially important outputs of the sun and the easily observed indices of solar activity, such as the sunspot number and cosmic-ray modulation; (3) a better knowledge of the real variability of solar inputs to the earth's atmosphere; and (4) full understanding of the coupling between the upper, the middle, and the lower atmosphere.

These needs are at the basis of the principal conclusions and recommendations of the National Research Council panel that (1) the subject of sun-weather and sun-climate relationships should be approached from more fundamental physical directions and addressed in the broader framework of solar-terrestrial physics and atmospheric sciences and (2) related reliable data must continously be gathered, extended, and carefully analyzed with objective mathematical tools in order to allow an appropriate formulation and modelling of the physical driving mechanisms.

In brief, this study provides an excellent overview of the highlights and a critical analysis of an important and difficult subject in climate that has given and probably will continue to give rise to much controversy.

A. Berger is head of the Institute of Astronomy and Geophysics Georges Lemaître of the Catholic University of Louvain-la-Neuve, Belgium.

Atmospheric Turbulence and Air Pollution Modelling

F. T. M. Nieuwstadt and H. Van Dop (Eds.), D. Reidel, Hingham, Mass., 370 pp., 1082, $43.50.

Reviewed by Wen-yih Sun

Atmospheric Turbulence and Air Pollution Modelling originates from a September 1981 short course at The Hague presented by seven outstanding specialists. The material has been combined and integrated by the editors.

The first two chapters cover the basic concepts, fundamental equations, and similarity relations applied in the planetary boundary layer. They provide a very important background for succeeding chapters. The first-order and the second-order closure schemes are discussed in chapter 3. Observational phenomena of free convection have been extensively covered in chapter 4. The subsequent three chapters treat the diffusion problems in both unstable and stable conditions. Various models, which include the Lagrangian model of diffusion, similarity model of diffusion, statistical model of diffusion, Gaussian plume model, and K-diffusion model are presented; the comparison of the results of some models with observations are also included. The last chapter is a report of panel discussion in which some useful remarks can be found.

The book is well written and concise, with extensive citations and cross-references within the book. There are very few errors. The list of symbols and notations is also quite helpful. Probably because many different topics are covered in a single volume, some models and phenomena are only briefly discussed. Hence, the subject matter does not always flow smoothly from one chapter to the next. In my opinion, some additional material should also be included, such as: the helical rolls and Benard cells in PBL and their influence on diffusion; comparison of the Ekman spiral and the real wind profile in the convective boundary layer; the influence of the horizontal inhomogeneity on the turbulence energy spectrum as well as the turbulence parameterization; and the numerical simulation of air pollution through a second-order closure scheme. It would also be helpful to have problems and answers at the end of each chapter.

When used under the guidance of an instructor and supplemented by original literature, this book could definitely be a useful text for graduate students who already have some background in fluid dynamics. As to meteorologists and environmental scientists, this book can be used as a review and a guide to recent literature on the subject.

In summary, I believe that the editors have accomplished their goal: "To bring the reader up to date on recent advances in boundary layer meteorology and to pave the path for applications in air pollution dispersion problems."

Wen-yih Sun is with the Department of Geosciences, Purdue University, West Lafayette, IN 47907.

The Natural Geochemistry of Our Environment

D. H. Speidel and A. F. Agnew, *Spec. Stud. in Nat. Res. and Energy Management*, Westview, Boulder, Colo., xv + 214 pp., 1982, $20.

Reviewed by Bryan Gregor

This small work sets out "to provide an overview of the earth that will enable earth scientists to gain an appreciation of how and where the work of scientists in other disciplines can be applied to earth-science problems" and to "provide an overview of the natural geochemical behavior of elements for the scientists in these other disciplines so that they, in turn, can use the work of earth scientists for their own problems." If these undeniably worthwhile aims have already been achieved in large measure by such familiar figures from the past as Vernadsky, Boltwood, Goldschmidt, and Holmes, there is nonetheless some justification for this otherwise unpretentious little book, which in fact focuses its attention on the chemical elements important to life. It contains a good deal of information, most of it reasonably up to date; among its most useful features are compilations of hydrographic data (mainly from Browzin, Meybeck, and Baumgartner and Ruedel) and of data from several recent publications on the chemical composition of land plants and on the global distribution of biomass and productivity. There are good explanations of the hydrologic cycle and of the effect of *p*H on the mobility of chemical species, and the chapter on soils is satisfactory at the elementary level to which it necessarily adheres in so short a treatment. Each chapter is followed by a comprehensive list of references, and the index is adequate.

Unfortunately, the writing is, on the whole, sloppy, with many rambling passages like the one quoted above. More careful attention to style would have made the text clearer and might have saved enough space to allow inclusion of some topics that are regrettably absent, such as atmospheric trace-element chemistry and the chemistry of underground water. In chapter 5 the discussion of marine sediments does not distinguish between continental margins and deep-sea floor; and Figure 5.5 (a map of deep-sea sediments in which the ocean floor extends right up to the coastlines) shows that this is no mere *lapsus calami*. Pointless terms like "lithogenous" for "detrital" and "hydrogenous" (already taken by Hamilton in 1791) for "authigenic" were better not perpetuated; the same probably goes for "geochemical ecology" (p. 2), an expression sure to make Haeckel turn in his grave. A good many of the figures are badly designed, and some have lettering too small to be read in comfort by this aging reviewer. The epilogue is a vague homily about accommodating our lives to the earth's geochemical cycles; the nature of the "moral dilemma," and the means by which we might escape it, remain obscure.

Get this book for its tables if you don't have access to the primary sources.

Bryan Gregor is with the Department of Geological Sciences, Wright State University, Dayton, OH 45435.

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Send letters of application, resume, and names and addresses of three professional references to: Roger L. Larson, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882.

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Bert E. Nordlie
Department of Earth Sciences
Iowa State University
253 Science I
Ames, Iowa 50011

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Oceanographers. Assistant Professor, tenure track position for applicants with recent Ph.D. and competence and interest in marine radioactivity and trace metal biogeochemistry. Duties will include development of research projects and some teaching. Salary negotiable depending upon experience and qualifications. Submit resume and names and addresses of three references by 1 September 1983 to: G. Ross Heath, Dean, School of Oceanography, Oregon State University, Corvallis, OR 97331.

An AA/EEO Employer.

University of Colorado, Boulder, Geochemist Position. Geochemist with active research program. stable isotopes, radioactive isotopes, and/or trace elements is being sought for a joint appointment in the Department of Geological Sciences and the Cooperative Institute for Research in Environmental Sciences (CIRES) of the University of Colorado.

The one-half time position within the Department of Geological Sciences is tenure track at the assistant or associate professor level with a starting salary of $12,000—$15,000 for the academic year.

Teaching load will be half that of full-time faculty. The position within CIRES will be as a Fellow with appropriate office and laboratory space. One-half academic year salary will be guaranteed by CIRES for two years at the departmental rate, after which incumbent must generate his/her CIRES salary from external sources. Incumbent may augment salary further by generating three months of summer salary from contracts and grants, and consulting.

Applicants with experience, publications, and/or movable existing research equipment preferred. Preferred starting date would be January 1, 1984. Closing date for applications is October 1, 1983.

Applications should include statement of research and teaching interests, experience, a full vitae, and four letters of reference.

Apply to: Professor Charles Stern, Chairman, Geochemist Search Committee, Department of Geological Sciences, Campus Box 25B, University of Colorado, Boulder, CO 80309.

The University of Colorado is an equal opportunity/affirmative action, Section 504 employer.

University of Minnesota Stratigrapher/Sedimentary Petrologist. Tenure-track position starting Fall 1984, probably at the Assistant Professor level. The candidate must have a Ph.D. with interest in stratigraphy of sedimentary basins, tectonics and sedimentation, and sedimentary petrology, and will be expected to carry out research and to teach graduate and undergraduate courses in these fields. Please submit resume, academic records, and three letters of recommendation to Dr. Peter J. Hudleston, Department of Geology and Geophysics, 108 Pillsbury Hall, University of Minnesota, Minneapolis, MN 55455 (612)373-3373.

The University is an Equal Opportunity/Affirmative Action Employer.

Iowa State University of Science and Technology, Department of Earth Sciences. Applications are invited for a tenure track faculty position in Meteorology. Rank is at the assistant or associate professor level, dependent upon qualifications. The successful applicant will be expected to develop a strong research and graduate student program and will teach undergraduate and graduate courses for meteorology majors.

The position is for a person with proven expertise within the general area of dynamic meteorology. Teaching will involve an undergraduate course in synoptic meteorology, in addition to courses related to the field of expertise. Completion of the Ph.D. prior to appointment is strongly preferred. In addition, research ability shown by other publications and/or postdoctoral experience will be an advantage.

Iowa State offers degrees in meteorology through the Ph.D. The program includes about 80 undergraduate majors; the graduate/research program is strong and emphasizes theoretical, dynamic studies. Close relationships are established with the facilities and personnel of major national laboratories. New campus facilities for meteorology are currently under construction.

The appointment is expected to begin no later than September, 1984; an appointment during the current academic year may be possible. Application deadline is November 1, 1983; later applications will be accepted if the position is not filled. For application information please write to:

Dr. Bert E. Nordlie
Department of Earth Sciences
Iowa State University
253 Science I
Ames, Iowa 50011.

Iowa State University is an equal opportunity/affirmative action employer.

Research Scientist/Atmospheric Science/MIT. The Center for Meteorology and Physical Oceanography at MIT seeks applications from new or recent Ph.D.'s in atmospheric sciences for a research position involving the interpretation of NIMBUS-7 and SAGE satellite data on stratospheric trace gases and aerosols. The general aim is to improve our understanding of stratospheric chemistry and of the three-dimensional and residual-mean two-dimensional transport of tracers in the upper atmosphere. Appointment duration is one to three years. Familiarity with computing techniques used in multi-dimensional atmospheric circulation models is necessary. Please send curriculum vitae and names of three references to: Professor Ronald G. Prinn, c/o Vera Ballard, MIT, E19–238, Cambridge, MA 02139.

MIT is an equal opportunity/affirmative action employer.

Hydrologist/Engineer. Participates in multidisciplinary research program to improve erosion prediction and erosion control. Primary emphasis on development of hydrologic concepts and mathematical relationships needed by fundamentally based erosion/sediment yield models for field sized areas. Career research position with U.S. Department of Agriculture at national Soil Erosion Laboratory on Purdue University campus in West Lafayette, Indiana. Minimum Salary: $24,508. For applications, contact Marie Bishop, USDA-ARS-NCR-M4, 2000 W. Pioneer Parkway, Peoria, IL 61615. Telephone 309-671-7134.

An Equal Opportunity Employer.

The University of Missouri-Columbia/Faculty Positions. The University of Missouri-Columbia Department of Geology plans immediate expansion through the addition of three tenure-track faculty positions. Appointments are anticipated at the assistant professor level, although higher ranks may be possible, beginning in August of 1984. Candidates will be expected to have completed requirements for the Ph.D. degree by that time. Faculty members are required to provide quality instruction at both undergraduate and graduate levels, and conduct research leading to scholarly publications. Successful candidates will be chosen from the following specialties:

Exploration Geophysics
Solid-Earth Geophysics
Hydrogeology
Analytical Structural Geology
Clastic Sedimentology

Applicants should send resume, transcripts, and names and addresses of three references to:

Tom Freeman, Chairman
Department of Geology
University of Missouri
Columbia, MO 65211.

Chairman—Department of Geological Sciences, Wright State University. The Department of Geological Sciences, invites applications for the position of chairman, to be appointed September 1984. We seek a dynamic individual with administrative talent and an appreciation for research and practice-related educational activities. Rank is at the full professor level and no restrictions have been placed on areas of specialization. The department is active with 12 faculty and an emphasis on professional practice, yet maintaining a firm commitment to basic research.

Send a letter of application, curriculum vitae and names of three references to:

Chairman, Search Committee
Department of Geological Sciences
Wright State University
Dayton, OH 45435.

Wright State University is an affirmative action/equal opportunity employer. Closing date for the position is October 31, 1983.

AGU

1983 John Adam Fleming Award

S. Keith Runcorn

Citation

Professor Runcorn's career began on a rather auspicious note. In the late forties, as a graduate student under Professor P. M. S. Blackett at Manchester, Runcorn demonstrated, along with others, that the intensity of the earth's magnetic field increases as you go into the earth. This was an outcome contrary to what Professor Blackett had predicted as a result of his theory on the generation of magnetic fields by rotating bodies—in this case, the earth.

After his graduate studies in Manchester, Professor Runcorn returned to Cambridge where he became a Fellow of Gonville and Caius College and Assistant Director of Research in Geophysics. Professor Runcorn and his students immediately set up a laboratory for the study of the magnetism of rocks using the sensitive astatic magnetometers developed by the Blackett group for research on the magnetism of rotating bodies.

It was during this period from 1950 to 1955 that Runcorn and his students laid the groundwork for understanding the history and origin of the earth's magnetic field. He argued for and presented data to demonstrate that the earth's magnetic field averages to a geocentric axial dipole. With his students he produced the first polar wandering curve based on a new statistical technique that he had persuaded and stimulated Sir Ronald Fisher to produce. He was an early advocate of field reversals and by 1956 became a supporter of the continental drift concept, one of the first geophysicists to do so.

Runcorn did not confine his interests in the magnetic field to paleomagnetism but attempted with his students to understand through model experiments on fluid motions in a rotating sphere how the earth's magnetic field is generated and propagated. It might be expected that after such an auspicious start his interest in the magnetic field would dissipate. However, instead of decreasing, it has expanded to include the generation of magnetic fields of the moon and in the solar system, which has resulted in several recent papers on polar wandering on the moon.

During his career his scientific achievements have been widely recognized by his peers. In 1965 he was elected as a Fellow of the Royal Society, and in 1971 he received the Vetlesen Prize from Columbia University.

I had the privilege of being one of Professor Runcorn's graduate students from 1955 to 1958, and during this time I got to know and appreciate his scientific and personal attributes. His mode of operation is in many respects unique. He is untiring in the pursuit of a scientific problem, and once he starts on one he literally thinks about it for 24 hours a day. He would exhaust his associates by going over the essentials of a problem at breakfast, lunch, and dinner as well as over a beer in the local pub. It can be very exhausting.

Undoubtedly, the most valuable lesson I learned as a student was that once you have determined that your experimental data are sound, you must then drive the data to their logical conclusion and support that conclusion even in the face of ridicule and unpopularity. During the time I was Professor Runcorn's student, he championed continental drift in opposition to what was essentially a hostile scientific community simply because that is what the data were saying. In the end, he was shown to be correct. However, it required a strength of character that few of us possess.

In view of his many contributions to understanding the earth's magnetic field and magnetism in the early history of solar systems, it's clear that Professor Runcorn richly deserves the John Adam Fleming Medal. We are confident that he will be a fruitful contributor to the field for many years to come.

Neil D. Opdyke

Acceptance

President, Ladies, and Gentlemen,

I am greatly honoured to receive the John Adam Fleming Medal. This award reflects the role geomagnetism and paleomagnetism have played in the last 25 years in replacing the static model of the earth's interior by a dynamic one.

I was most fortunate in those English scientists, especially Professor P. M. S. Blackett, Sir Ronald Fisher, Professor S. Chapman, and Sir James Chadwick, who gave me much encouragement when I began [illegible] I was most fortunate in having contemporaries fascinated by the problems of paleomagnetism: J. G. Graham, A. Cox, and R. R. Doell here, and J. A. Clegg in Britain. I was especially fortunate in my research students whose interests have ranged from mathematics to biology; among the earliest, J. Hospers, E. Irving, N. D. Opdyke, K. M. Creer, and D. W. Collinson in paleomagnetism and F. J. Lowes, R. Hide, P. H. Roberts, and D. G. Tozer in studies of the dynamics of the earth's interior have been internationally recognized in various ways. This has been one of the most pleasant aspects of my academic career.

I recall meeting Dr. Fleming at the first IUGG that I attended, in Oslo, 1948; he showed a slide of the westward drift of the geomagnetic isoporic foci (1912–42) from the geomagnetic maps which the Department of Terrestrial Magnetism had compiled. This rediscovery, Blackett's speculative theory of the main geomagnetic field, and W. M. Elsasser's and E. G. Bullard's dynamo theory—all in the immediate postwar years—reopened a subject which had been essentially dead for a over a century since Gauss's work.

We started our paleomagnetic work in Britain with the foundations of the physics of the subject well laid by E. Thellier, T. Nagata, and L. Neel, but in our most optimistic moments we could not have imagined the wonderful developments which have occurred, not least in recent years and in the sophistication of measurement techniques and analysis in the detailed geological applications. We were like archeologists who, stumbling over a few stones, began to excavate and, joined by others, uncovered a whole new civilization. In fact the field has now become very crowded and competition great, and a few of us, backed by NASA, have sought refuge in the moon, where paleomagnetism is now revealing as interesting a story as the earth—and an even older one!

Neil Opdyke's very generous citation refers to opposition. It was not surprising that many were skeptical about paleomagnetism; how extraordinary that such a feeble force as the geomagnetic field should have laid such a lasting imprint on rocks! Professor L. Hawkes, typical of many distinguished geologists who helped us, once said to us: "When I was a student, rocks just contained minerals; when I began research I learned to my astonishment that they emitted radioactive particles; now you are telling me they possess lines of magnetic force—rocks are wonderful things!"

And how surprising too that the one characteristic of the geomagnetic field that we can prove to be fundamental—the axial dipole—is that which made it the tool to investigate continental drift.

I am particularly pleased to receive this award from AGU. My second visit to the U.S.A. was the result of an invitation from the AGU President, Walter H. Bucher, a great natural scientist and a wide ranging thinker, who invited me to take part in a special session at the annual meeting in Washington in 1958. I think he must have been criticised for bringing in such a young, unknown scientist, as he was moving [illegible] emphatically, "I believe in giving the young the opportunity to put their ideas forward." This has been a characteristic of AGU and, when a few years later, we thought it timely to set up the European Geophysical Society, we took many ideas from AGU, and both the present and past Executive Secretaries and other officers have been most helpful.

One ought not to boast about one's achievements on such an occasion, but I cannot resist: My early collection of rocks in the Grand Canyon established the basic principle of paleomagnetic research which has been followed by its practitioners ever since: one should only collect rocks in beautiful places far from one's home base. Dr. Opdyke, whom I would like to have thanked in person for his citation, was a good student: He is at present in China. Thinking of the fascinating paleomagnetic sessions in recent AGU meetings, it is most fortunate that, for this early comparison of U.S. and British polar wandering curves, I did not choose to do it in one of the displaced terrains of the northwest of this continent: I would have set back the subject for 20 years!

S. Keith Runcorn

Membership Applications Received

Applications for membership have been received from the following individuals. The letter after the name denotes the proposed primary section affiliation; the letter A denotes the Atmospheric Sciences section, which was formerly the Meteorology section.

Ernest J. Daddio (O), Denis Damore (H), James E. Eckman (O), David Edwards (S), James H. Eychaner (H), Colin G. Ferguson (T), Gary T. Fisher (H), Bruce Herbert Gardner (S), Boris Gelchinsky (S), Keith Dennis Gerdes (T), Samuel Mandel (H), Phillip L. McFadden (GP), Christine Morshedi (S), Victor S. Reinhardt (G), Arthur P. S. Reynier (T), Robert W. Talbot (O), Zyryanov Vladislav (V), Hui An Yin (V).

Student Status

Craig R. Bina (V), Stephen Brewer (S), Dimar Brumenleks (GP), Gregory Burgess (T), Jorge E. Capella (O), Allan B. Carswell (G), Jin-Song Chen (H), Jing-Jong Chen (S), John J. Dwyer (S), Marybeth Hulit (S), Nai Gio Lin (SM), Jerry F. Magloughlin (T), Carolyn Ng (T), Jens W. Otto (V), William B. Pucket (H), Stephen H. Richardson (V), Marion Redeout (V), Larry T. Rollins (H), Delbert H. Stark (H), Susan F. Sugal (O), Lynn M. Vogel (V), Jim Weaver (H), Thomas White (O), Steven L. Winters (H), Steven L. Woodall (H), Robert Woodward (S).

Meetings

Announcements

Magnetospheric Systems

A conference on the ionized environments of planetary, astrophysical objects is being planned for the summer of 1985. The meeting, called the "Colloquium on Comparative Study of Magnetospheric Systems," aims to provide a comparative interdisciplinary exchange on topics such as planetary magnetospheres, pulsars, and quasars. Emphasis will be on the common physical processes occurring in astrogeophysical systems.

Among the proposed topics for the meeting are the terrestrial magnetosphere; magnetosphere of giant planets; magnetosphere of pulsars; plasma environment of unmagnetized planets; origin of magnetospheric plasmas; comparative study of plasma circulation inside magnetospheres; coupling between magnetospheres and external sources (including dynamical properties of plasma sheets and magnetospheres as plasma sources inside stellar winds); coupling between magnetospheres and internal sources (including origin and structure of the auroral arcs, electron acceleration processes inside localized structures, and ion acceleration); electromagnetic emissions from pulsars; the sporadic radio emission from planets; and ultraviolet and optical emissions.

For additional information, contact Dominique Le Quéau and Bent Møoller-Pedersen, DASOP, Observatoire de Meudon, F 92195, Meudon Principal Cedex, France (Telex: 200 590 CNET OBS).

Sediment Congress

The 12th International Sedimentological Congress, entitled "Sediments Down-Under," will be held August 25–29, 1986, in Canberra, Australia. In addition to the scientific program, seven short, geological excursions are planned.

Among the topics to be covered are ancient and modern arid environments; low-gradient river systems and their sediments; sedimentation in tectonically active areas; catastrophism in the sedimentary record; volcanogenic sediments; reef carbonates; and weathering and economic geology.

Depending on the interests of the participants, 19 field trips (each 1 to 2 weeks long) will be organized for before or after the congress.

Australia provides a varied sedimentary record. The Archean and early Proterozoic sediments of western and northern Australia provide evidence of some of the earliest life on earth. The classic exposures of the Flinders Ranges of South Australia provide a good record of late PreCambrian metazoan evolution. And some of the world's most complete Lower Paleozoic cratonic sequences are found in the Amadeus and Georgina Basins. In addition, the world-famous Devonian reefs of the Canning Basin provide an opportunity to examine a major reef system.

For additional information, contact Graham Taylor, P.O. Box 1929, Suite 19, BMI Building, Canberra City, ACT 2601, Australia.

Plan to Attend
The AGU Chapman Conference on Magnetic Reconnection

October 3-7

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Convenor: E. W. Hones, Jr.

Magnetic Reconnection was identified 5 years ago, in a study sponsored by the NAS Space Science Board, as a problem vital to further understanding of space plasmas and having important implications beyond the study of solar system plasmas. The forthcoming conference examines our present understanding of magnetic reconnection as a physical process and our perception of its roles in planetary and stellar magnetospheres (particularly those of the earth and sun) and in laboratory and fusion research. Specifically, there will be sessions devoted to theory, modeling, earth's magnetopause and magnetotail (including talks on ISEE 3 observations in the distant tail), fusion research, and astronomical objects (sun, comets, and Jupiter).

The registration fee, $65 ($32.50 for students), includes the conference banquet and picnic.

Some student travel funds still remain. To apply, write to Magnetic Reconnection Meeting, American Geophysical Union, 2000 Florida Avenue, N.W., Washington, DC 20009, giving your educational background and your research interests.

Write or telephone the convenor (505-667-4727) to obtain copies of the program, registration and housing forms, or other information. The deadline for housing reservations is September 9; the deadline for meeting registration is September 19.

GAP

Separates

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American Geophysical Union
2000 Florida Avenue, N.W.
Washington, D.C. 20009

Exploration Geophysics

0930 Seismic methods
THE EFFECTS OF STREAMER FEATHERING ON STACKING
[illegible]

Hydrology

[illegible]

Mineralogy, Petrology, and Crystal Chemistry

4510 Instruments and techniques
[illegible]

(... stopped down to the angular aperture of the opaque dot, produces a dark field on which the image of the fragment is outlined ... [illegible])
Am. Min., 68, 9–10

Oceanography

4729 Properties of minerals
WATER IN MINERALS? A PEAK IN THE INFRARED.
G. R. Aines and G. R. Rossman (Department of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, 91125)
[illegible]

4790 Instruments and techniques
AN INTERPOLATING GAPPY RECORDS FOR TIME-SERIES ANALYSIS
V. Sturges (Oceanography Department, Florida State University, Tallahassee, FL 32306)
[illegible]
J. Geophys. Res., Green, Paper 3C1194

Particles and Fields—Ionosphere

5515 Aurorae
ANOMALOUS RESISTIVITY DUE TO LOW FREQUENCY TURBULENCE
[illegible]

5530 High-latitude ionospheric currents
INFERRING ELECTRIC FIELDS AND CURRENTS FROM GROUND MAGNETOMETER DATA
[illegible]

Particles and Fields—Magnetosphere

5535 Interactions between waves and particles
[illegible]

5750 Plasma motion, convection, or circulation
CHARACTERISTICS OF THERMAL AND SUPRATHERMAL IONS ASSOCIATED WITH THE DAYSIDE PLASMA TROUGH AS MEASURED BY THE DYNAMICS EXPLORER RETARDING ION MASS SPECTROMETER
[illegible]

Planetology

6599 Miscellaneous (Rings)
THE INNER EDGE OF SATURN'S B RING
[illegible]
J. Geophys. Res., Blue, Paper 3A0732

6399 Planetology General (Planetary Rings)
VOYAGER PHOTOPOLARIMETER STELLAR OCCULTATION OF SATURN'S RINGS
[illegible]